Evaluation of satellite data assimilation impacts on mesoscale environment fields within the hourly cycled Rapid Refresh

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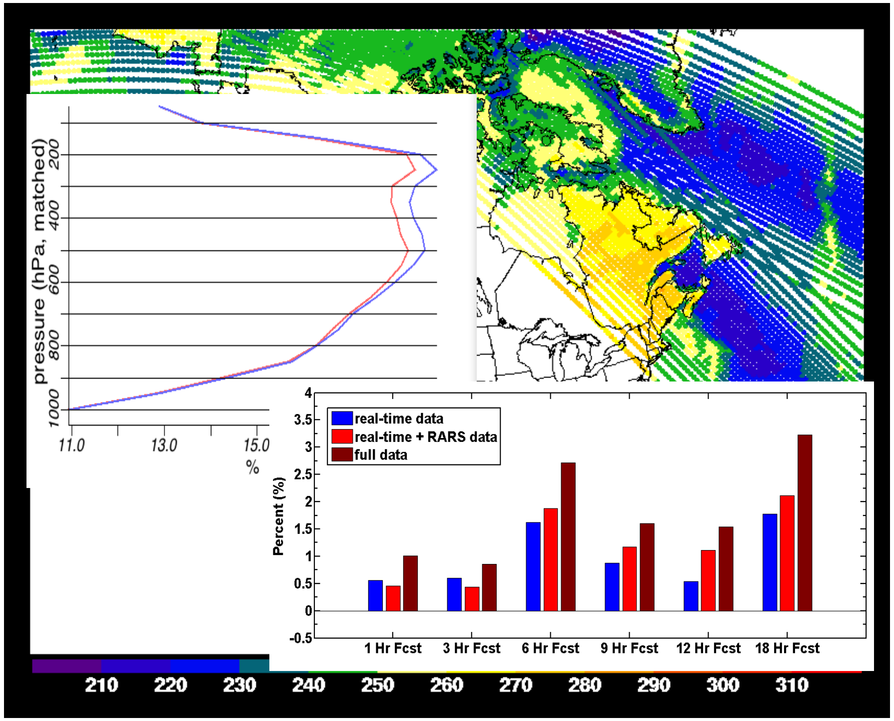


Presentation Outline

1. Background on Rapid Refresh (RAP) system
2. Background on regional radiance assimilation
   → satellite data types (geo / LEO, IR / microwave)
   → bias correction, channel selection, latency
3. Satellite radiance experiments
   - AIRS and GOES impact in RAP (retrospective)
     - upper air and precipitation verification
   - Sensitivity to data latency (retrospective)
     - upper air and precipitation verification
   - **Real-time radiance impact in RAP**
     - upper air verification and Impact on HRRR (retro)
4. Summary and future work

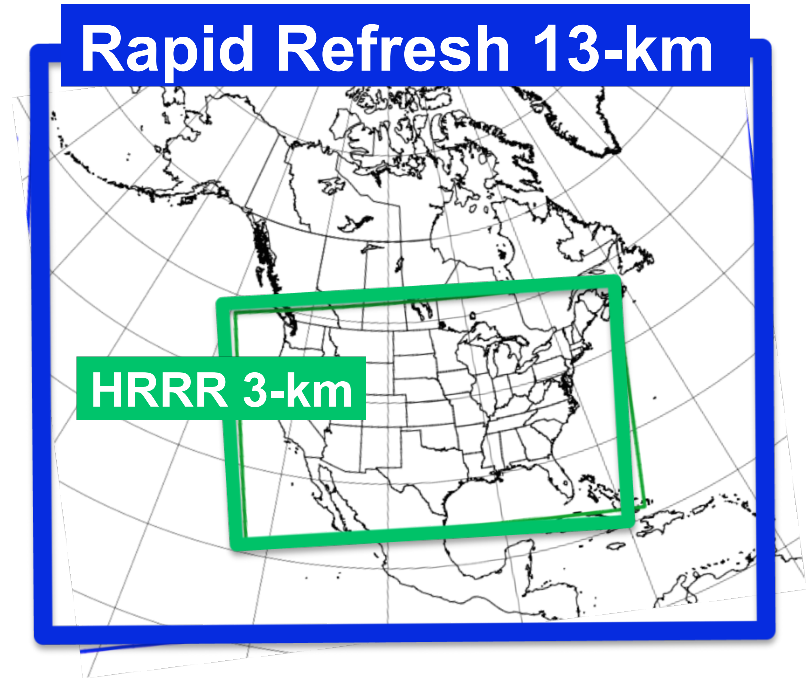
Background on Rapid Refresh
NOAA/NCEP's hourly updated model

RAP version 1 -- NCEP since Spring 2012
- Advanced community codes (ARW model, GSI analysis)
- Key features for short-range "situational awareness" application (cloud analysis, radar DFI assimilation)

➔ RAP guidance for aviation, severe weather, energy applications

RAP version 2 --
implemented NCEP 25 Feb. 2014
- DA enhancements (Hybrid – EnKF using global ensemble)
- Model enhancements (MYNN PBL, 9-layer LSM)

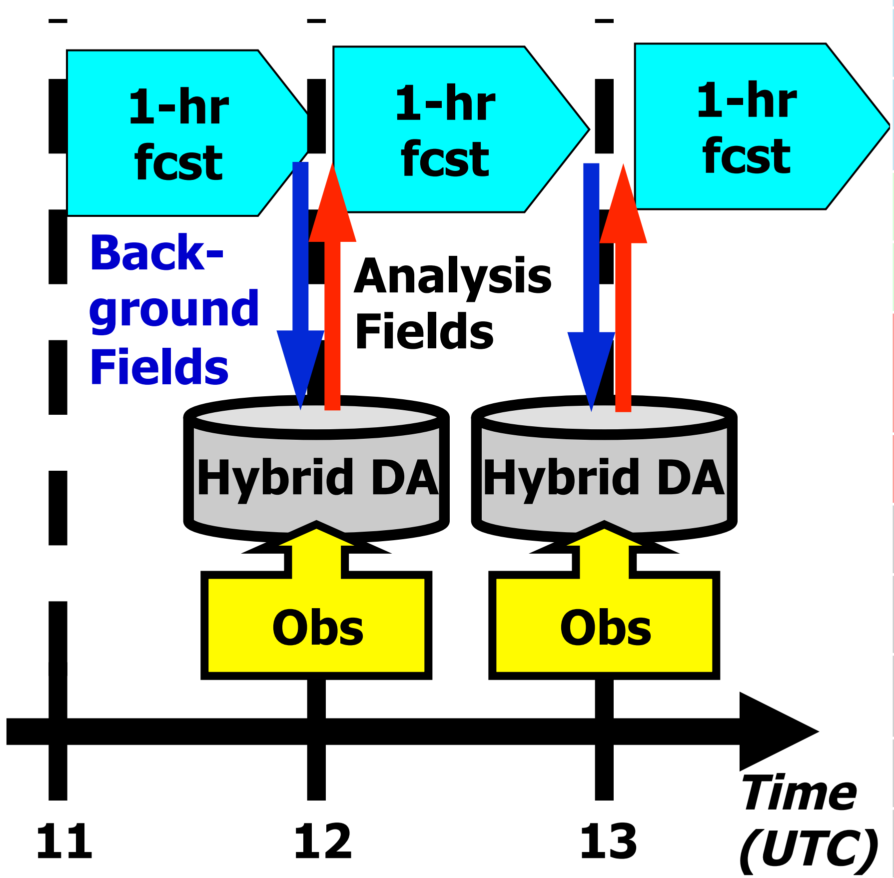
RAP version 3 -- free for GSD summer evaluation



Rapid Refresh Hourly Update Cycle

Partial cycle atmospheric fields – introduce GFS information 2x/day

Fully cycle all land-sfc fields



Observations Used

Hourly Observations	RAP 2014 N. Amer
Rawinsonde (T,V,RH)	120
Profiler – NOAA Network (V)	21
Profiler – 915 MHz (V, Tv)	25
Radar – VAD (V)	125
Radar reflectivity - CONUS	1km
Lightning (proxy reflectivity)	NLDN, GLD360
Aircraft (V,T)	2-15K
Aircraft - WVSS (RH)	0-800
Surface/METAR (T,Td,V,ps,cloud, vis, wx)	2200- 2500
Buoys/ships (V, ps)	200-400
GOES AMVs (V)	2000- 4000
AMSU/HIRS/MHS radiances	Used
GOES cloud-top press/temp	13km
GPS – Precipitable water	260
WindSat scatterometer	2-10K

Radiance Data

- **AMSUA (used in operational RAP)**
  - Temperature and moisture information
- **MHS (used in operational RAP)**
  - Temperature and moisture information
- **HIRS4 (used in operational RAP)**
  - Temperature information
  - Moisture information (channels 10-12)

Challenge to show impact from radiance assimilation within the "full mix of observations"

- **AIRS (not in operational RAP, testing data)**
  - High vertical resolution (hyperspectral)
  - Temperature and moisture information
- **GOES (not in operational RAP, in RAP V3)**
  - Temperature and moisture information
  - Good hourly real-time coverage

Measure improvement in upper-air verification and sensible weather

Radiance Assimilation for RAP

Challenges for regional, rapid updating radiance assimilation

- **Bias correction**
  - **-- Sophisticated cycled predictive bias correction in GSI**
  - **-- Spin-up period, complicated by non-uniform data coverage**
- **Channel Selection**
  - **Many channels sense at levels near RAP model top (10 mb)**
  - **Use of these high peaking channel can degrade forecast**
  - **Jacobian / adjoint analysis to select channels for exclusion**
- **Data availability issues for real-time use**
  - Rapid updating regional models: short data cut-off, small domain
  - Above combined with large data latency ➔ little data availability
  - Complicates bias correction, partial cycle assimilation options

Variational Satellite Bias Correction in GSI

$$J(x,\beta) = \tfrac{1}{2}(x - x_b)^T B^{-1}(x - x_b) + \tfrac{1}{2}(\beta - \beta_b)^T B_\beta{}^{-1}(\beta - \beta_b)$$

$$+ \tfrac{1}{2}[y - \tilde{H}(x,\beta)]^T R^{-1}[y - \tilde{H}(x,\beta)]$$

B_β Bias parameter background error covariance matrix

$$\tilde{H}(x,\beta) = H(x) + \sum_{i=0}^{N} \beta_i p_i(x) + b^{scan}$$

Observation Operator (CRTM)

Air mass bias

Angle bias

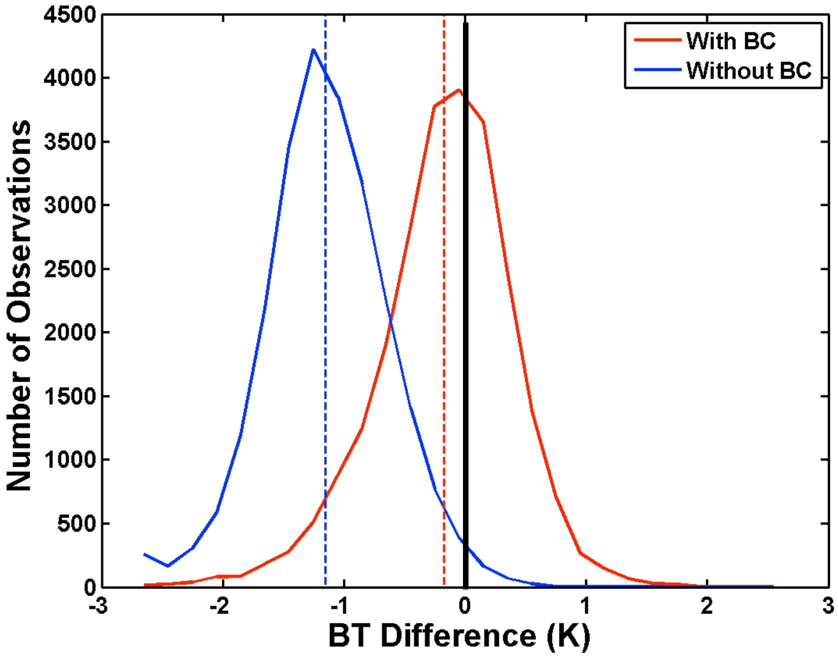
β_i are the coefficients of predictors (updated at every cycle)

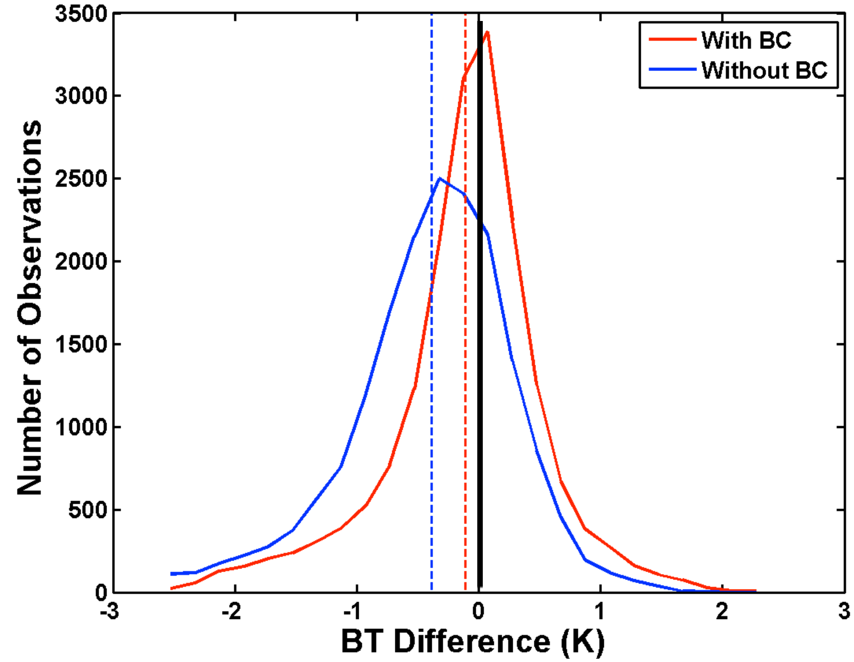
p_i = **predictors**

- mean constant (global offset)
- scan angle
- cloud liquid water (for microwave)
- square of T lapse rate
- T lapse rate

(Derber et al., 1991, Derber and Wu, 1998)

AIRS Bias Correction Assessment





Before BC

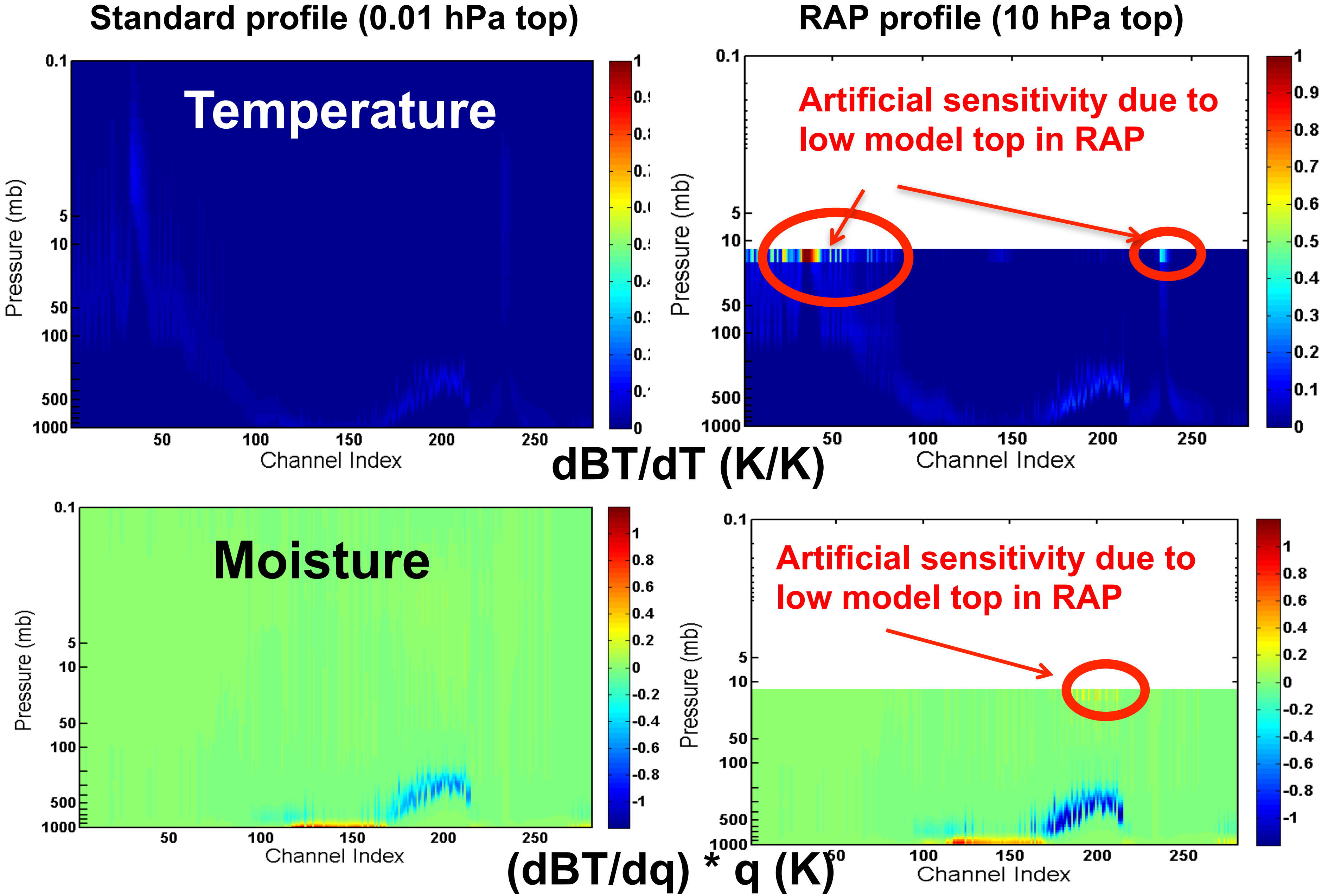
After BC

channel 252 (CO2 channel ~672h Pa

Channel 1382 (water vapor channel ~866 hPa

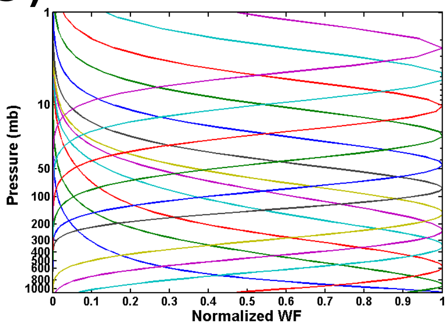
9 day retro run averaged

Satellite Channel Selection for RAP



Radiance Channels Selected for RAP

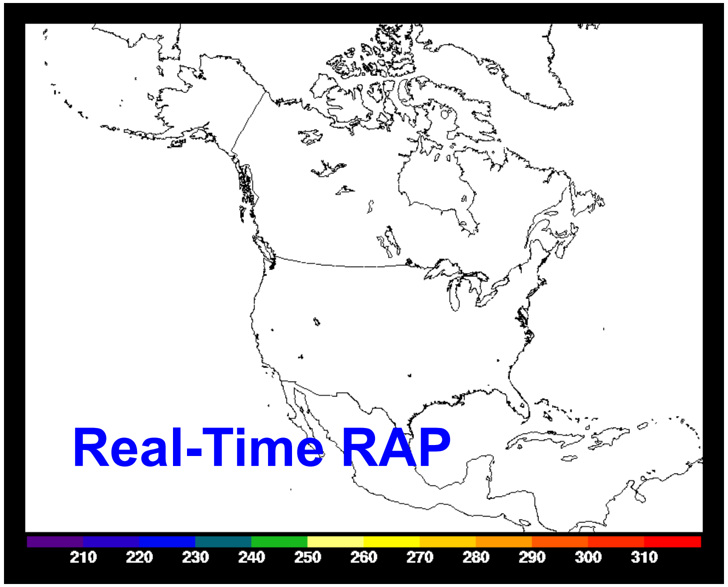
- **AMSU-A** (remove high-peaking channels)
  - metop-a: channels 1-6, 8-10, 15
  - noaa_n15: channels 1-10, 15
  - noaa_n18: channels 1-8, 10,15
  - noaa_n19: channels 1-7, 9-10,15

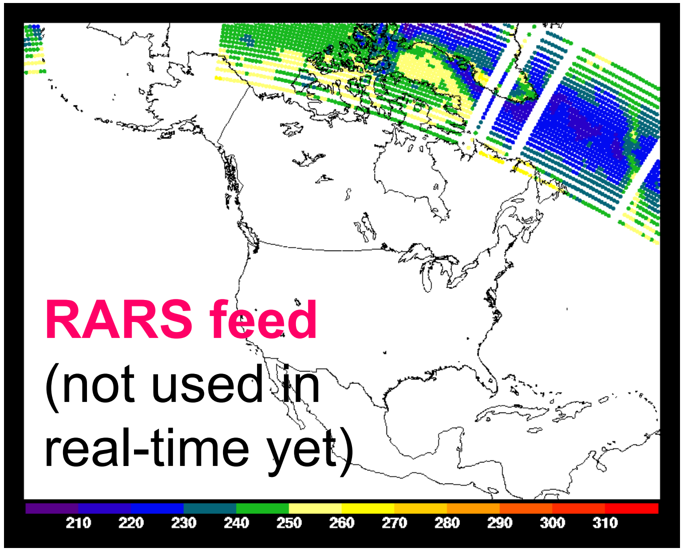


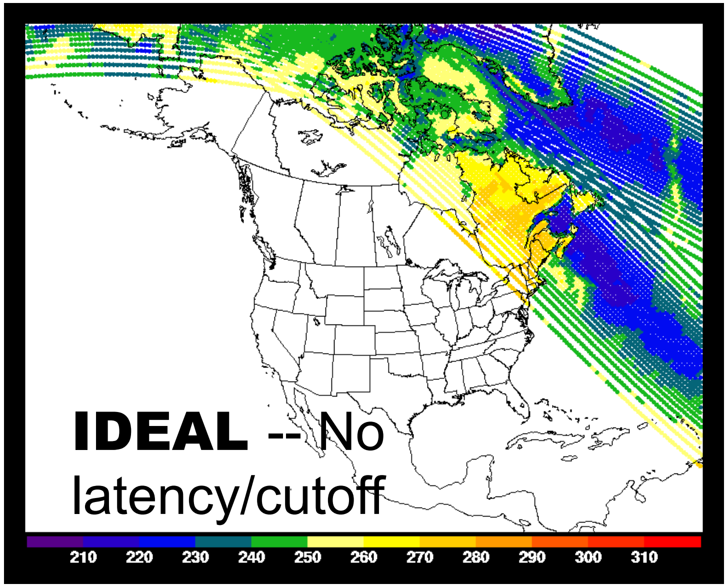
- **HIRS4** (remove high-peaking and ozone channels)
  - metop-a: channels: 4-8, 10-15
- **MHS**
  - noaa_n18, metop-a: channels 1-5;

- **AIRS** (remove high-peaking channels)
  - Aqua: 68 channels selected from 120 GDAS channel set
- **GOES** (remove high-peaking channels and ozone channel)
  - GOES-15 (sndrD1, sndrD2, sndrD3, sndrD4): channels 3-8,10-15

Real-Time Data Availability -- RARS







18Z May 29, 2013

RARS = Regional ATOVS Retransmission Services

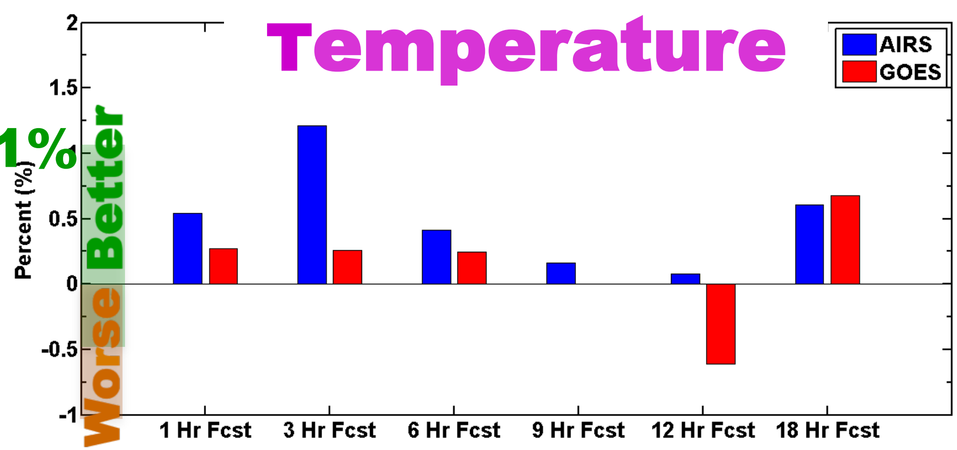
Assuming **+/- 1.5 h** time window

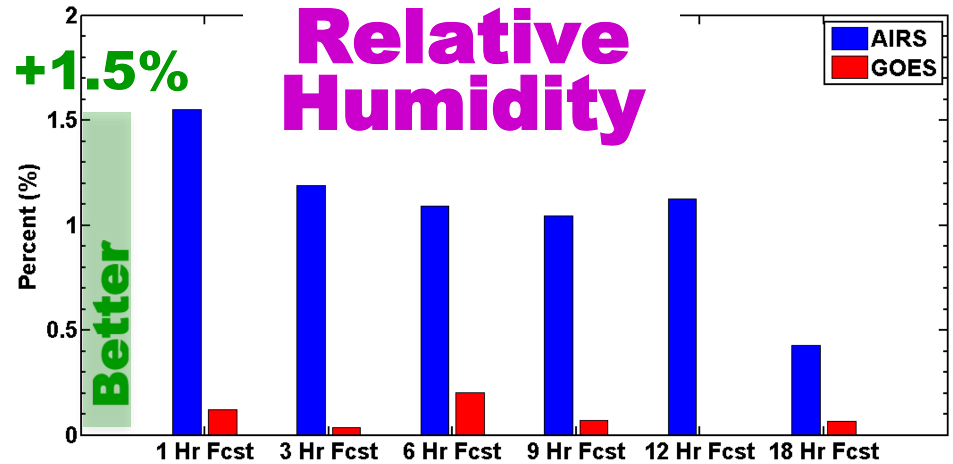
AMSU-A channel 3 from NOAA_18

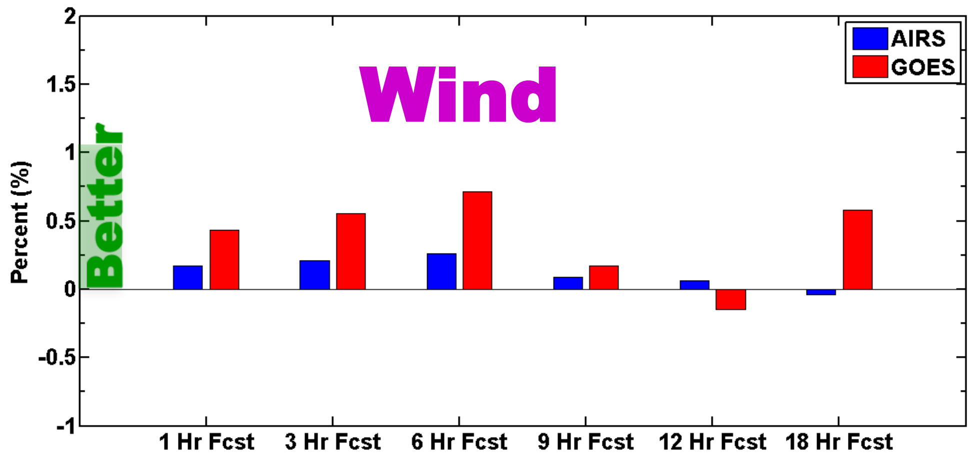
Retrospective Experiments
Set I: new sensors

- **Extensive retro run for bias coefficients spin up**
- **Control run (CNTL) – Conventional data only**
  - 1-h cycling run, 8-day retro run (May 28 – June 4 2012)
  - Hybrid EnKF RAP system
- **AIRS radiance experiment**
  - CNTL + AIRS radiance data (no latency)
  - Using 68 selected channels for RAP
- **GOES radiance experiment**
  - CNTL + real time GOES 15 radiance data (sndrD1,sndrD2,sndrD3, sndrD4)

Impact from AIRS and GOES data (against raob 100-1000 hPa)







AIRS

GOES

Normalize Errors

$$E_N = \frac{(CNTL - EXP)}{CNTL}$$

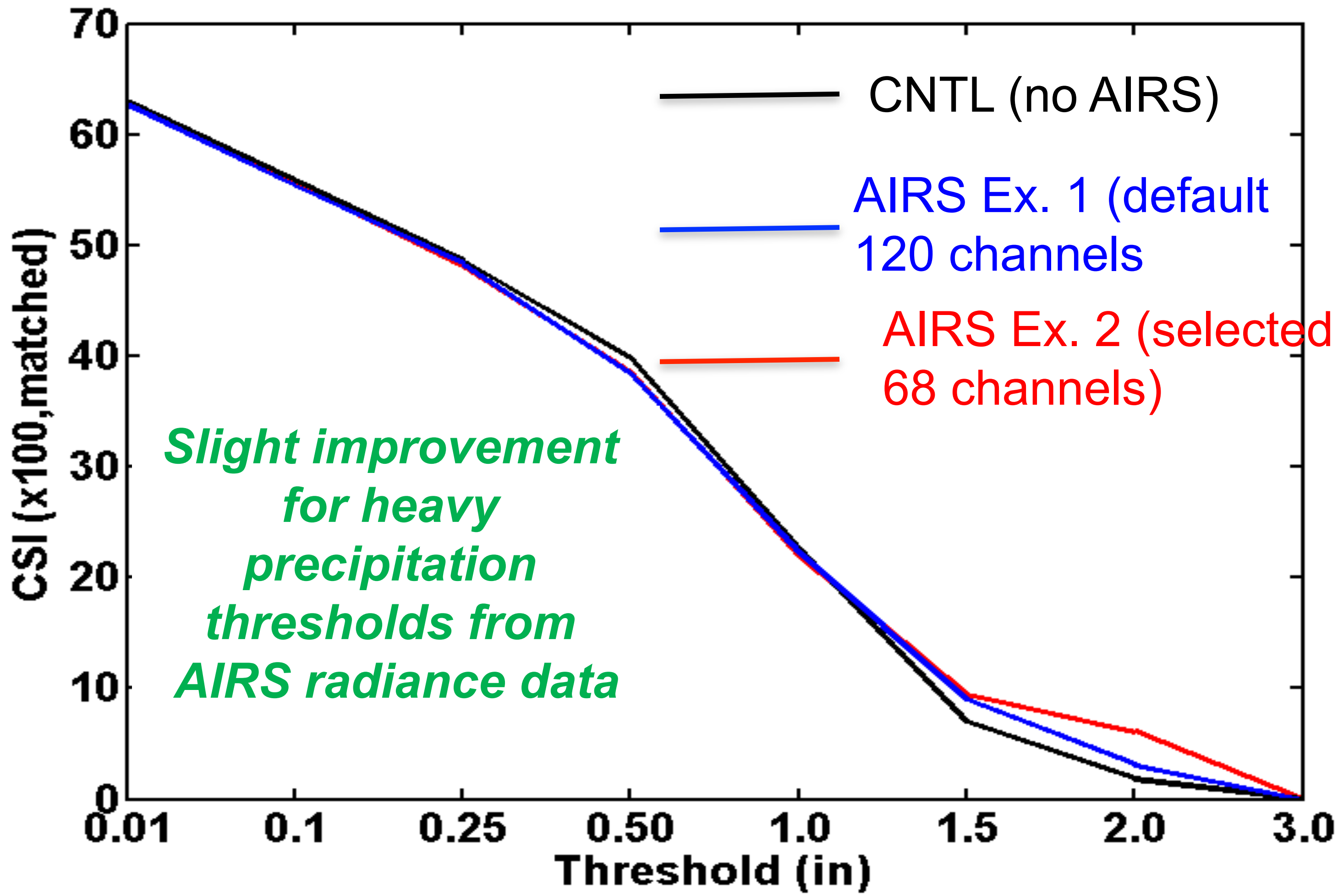
100-1000 hPa RMS mean

May28-June04 2012

upper-air verification

24-h (2 X 12h) CPC Precipitation Verification

CSI by precip threshold
(avg. over eight 24h periods)



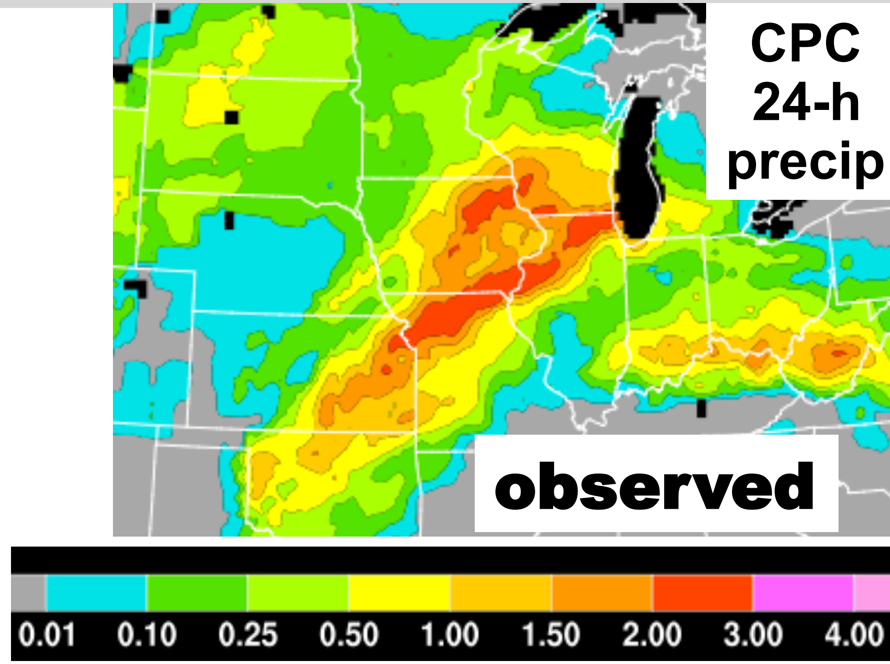
May08-June16 2010

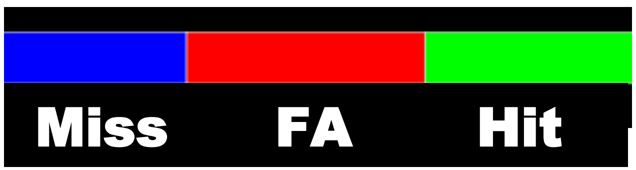
Sample Precipitation Impact

CNTL
vs.
AIRS
Ex. 2
24-h
precip.
verif

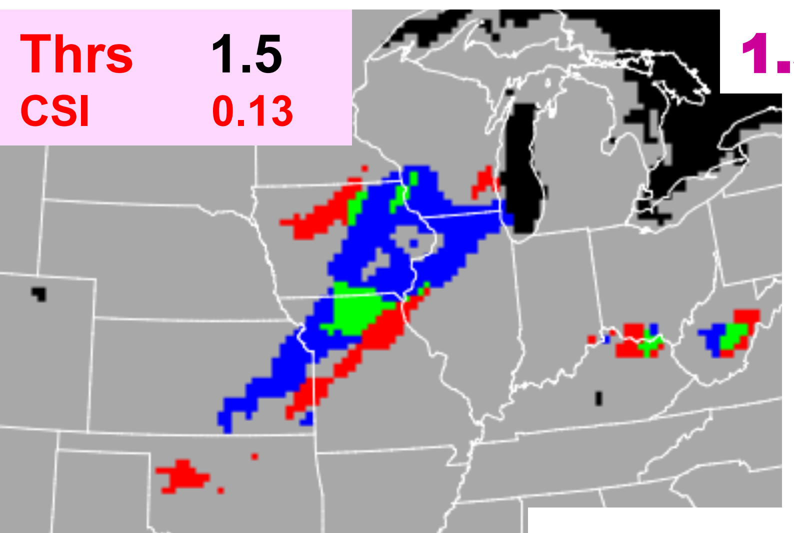
2 x 12h fcst
ending 12z
13 May 2010

Verified on
common
20-km grid

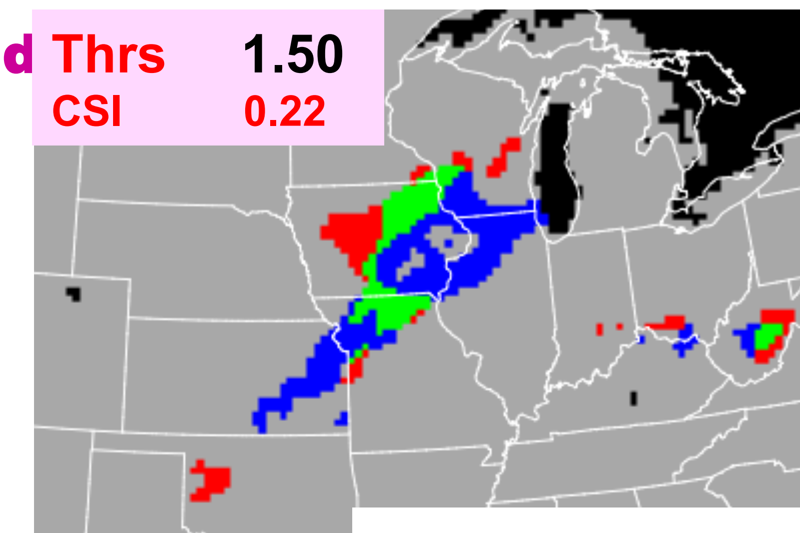




1.5 " theshold



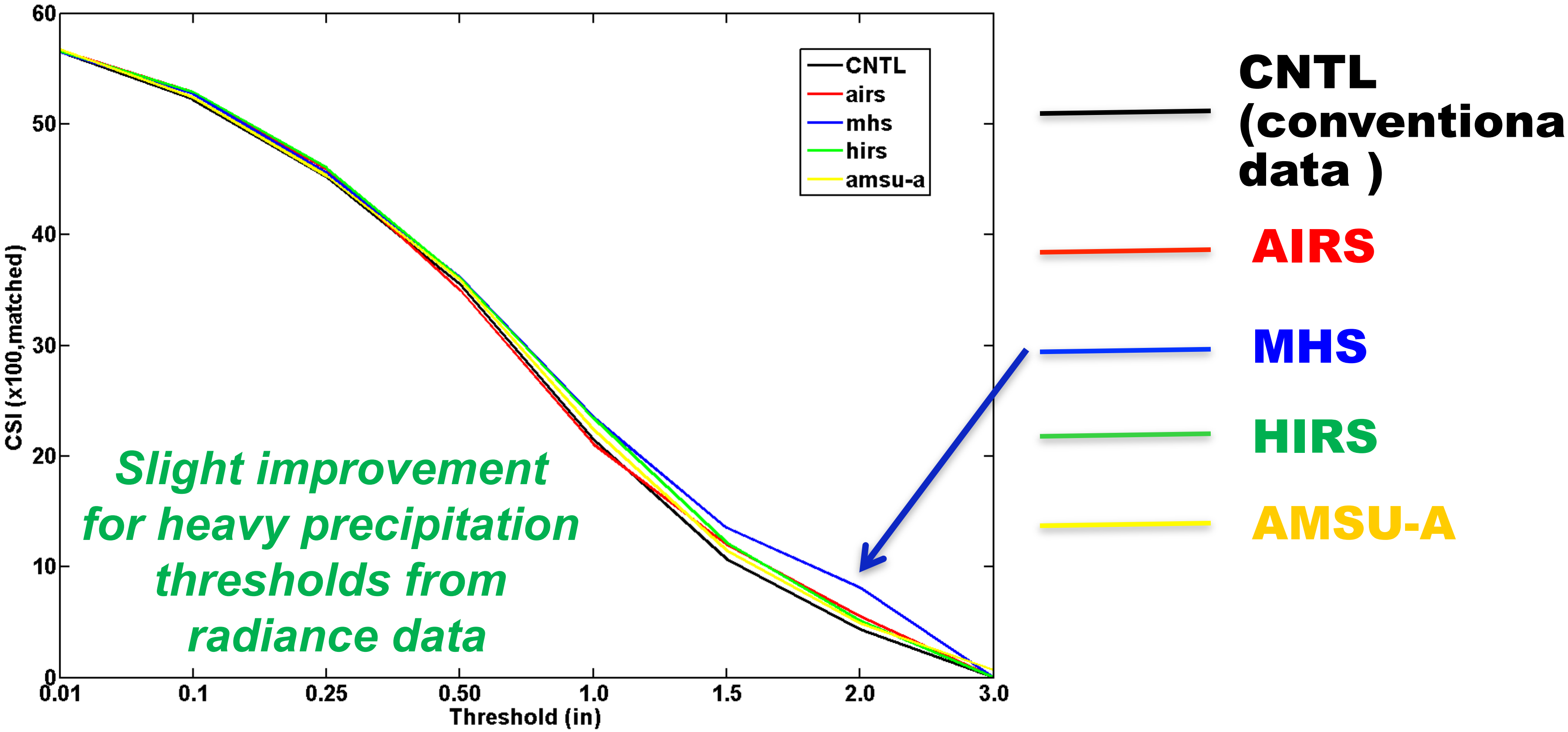
CNTL



AIRS Ex. 2

24-h (2 X 12h) Precipitation Verification

CSI by precip threshold
(avg. over eight 24h periods)



MHS data have largest positive impact for heavy precipitation prediction

May08-June16 2010

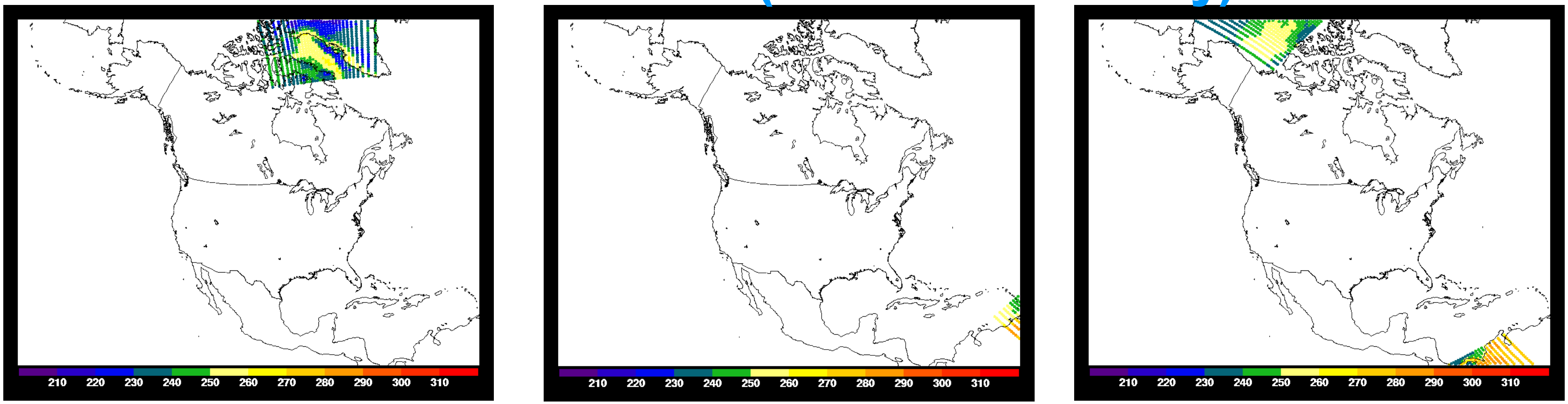
Retrospective Experiments
Set II (different data files)

- **Extensive retro run for bias coefficients spin up**
- **Control run (CNTL) – (conventional data only)**
  - 1-h cycling run, 8-day retro run (May 28 – June 4 2012)
  - RAP Hybrid EnKF system
- **Real-time radiance (limited availability)**
  - CNTL + RAP real time radiance data (amsua/mhs/hirs4/goes)
  - Use updated bias coefficients from the extensive retro run
- **RARS + Real-time radiance (better availability)**

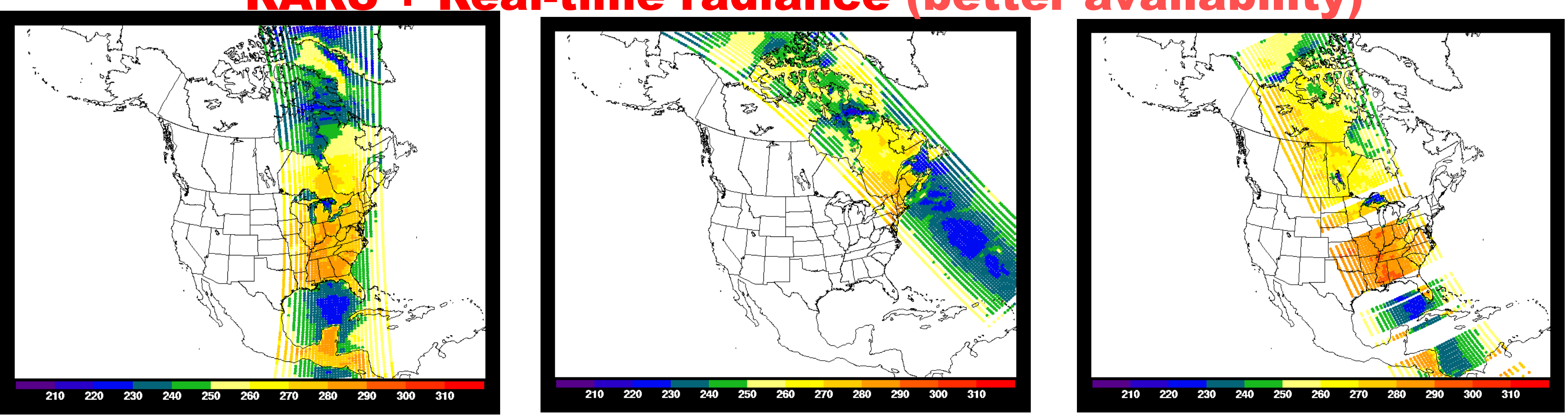
  (RARS = Regional ATOVS Retransmission Services)
- **Full coverage radiance (perfect availability)**
  - The same as experiment two but using full data for amsua/mhs/hirs4 (no data latency)

Coverage comparison for the RARS data and the regular feed data

Real-time radiance (limited availability)



RARS + Real-time radiance (better availability)

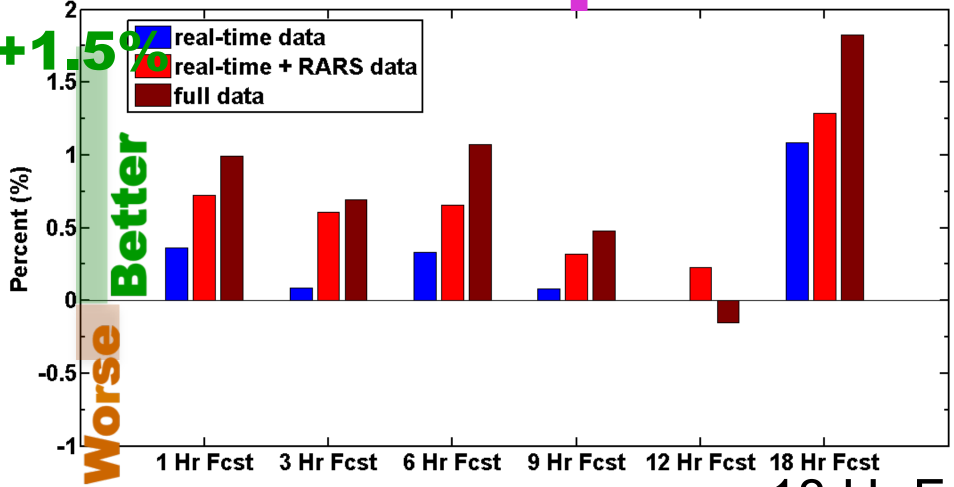


08Z 18Z 19Z

May 29 2012 amsua noaa-19

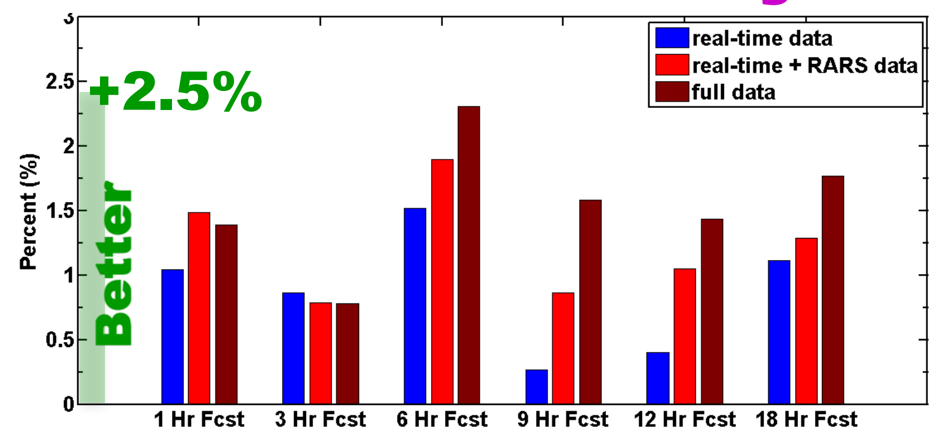
Impact from different data sets

Temperature



18 Hr Fcst

Relative Humidity

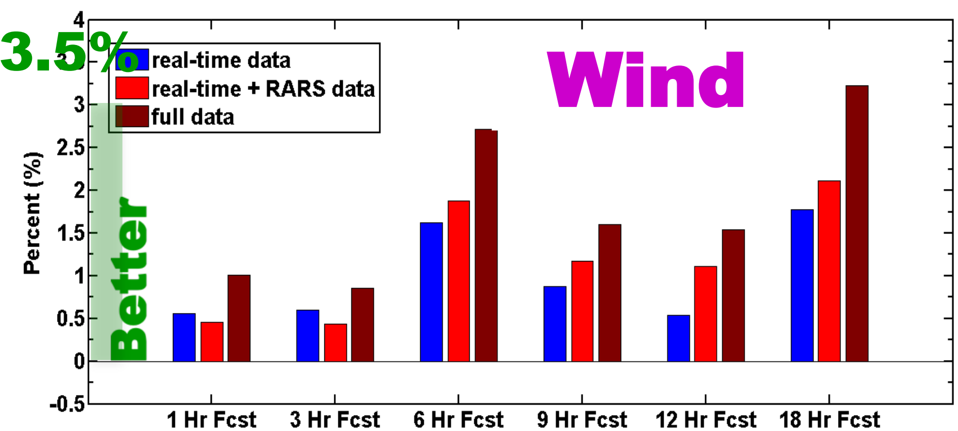


18 Hr Fcst

Real-time data

RARS included

Full data



18 Hr Fcst

100-1000 hPa RMS mean

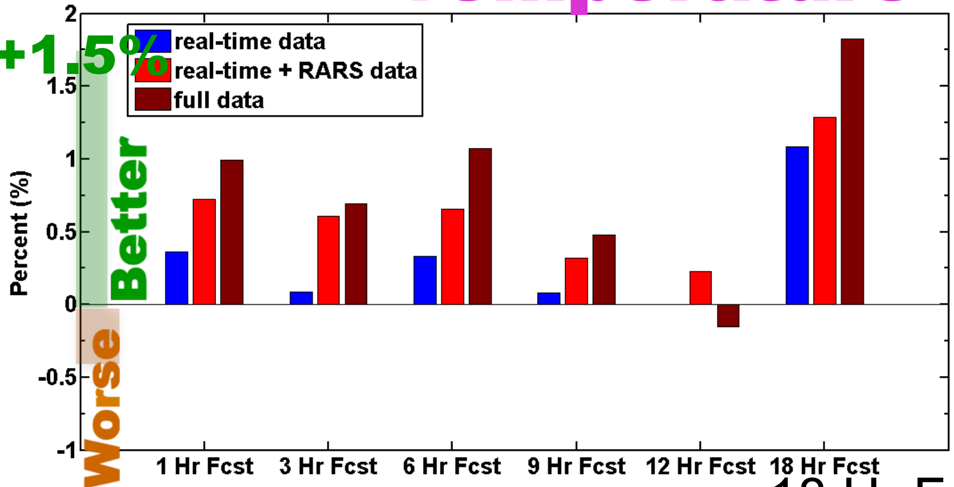
May28-June04 2012 retro runs

Normalize Errors

$$E_N = \frac{(CNTL - EXP)}{CNTL}$$

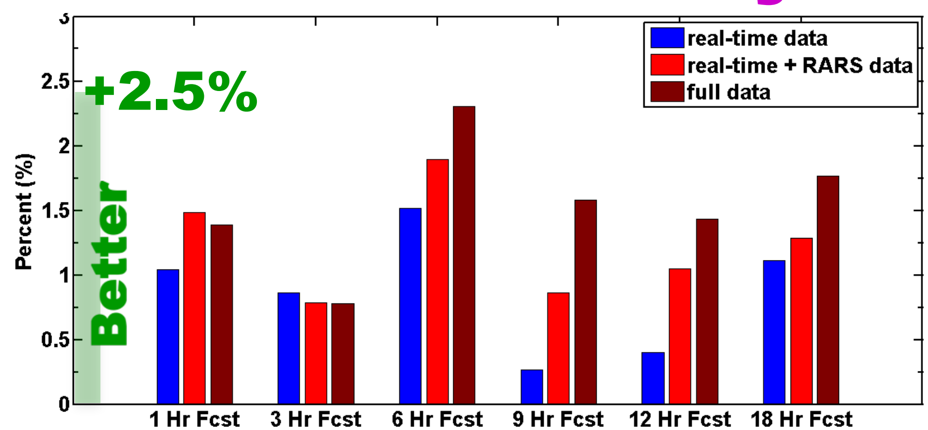
Impact from different data sets

Temperature



18 Hr Fcst

Relative Humidity



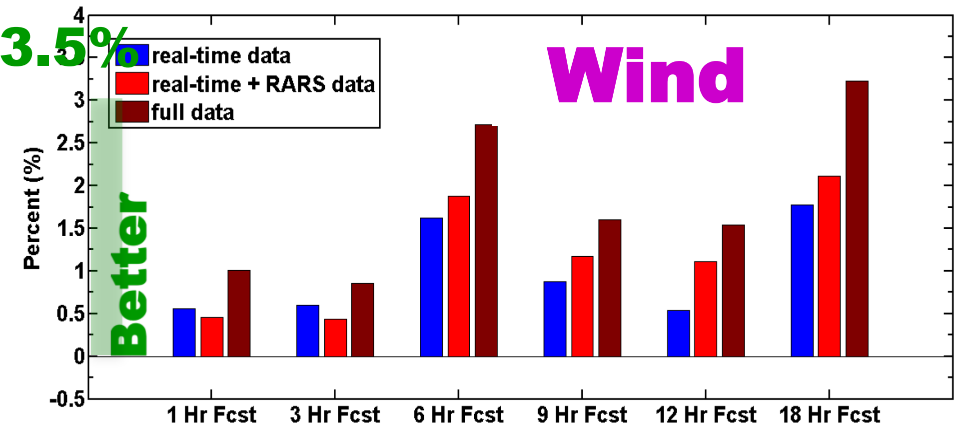
18 Hr Fcst

Real-time data

RARS included

Full data

Wind



18 Hr Fcst

Init Hour	11,23z	9,21z	6,18z	3,15z	0,12z	18,6z
Fcst length	1	3	6	9	12	18
Hrs since GFS	2	0	9	6	3	9

100-1000 hPa RMS mean

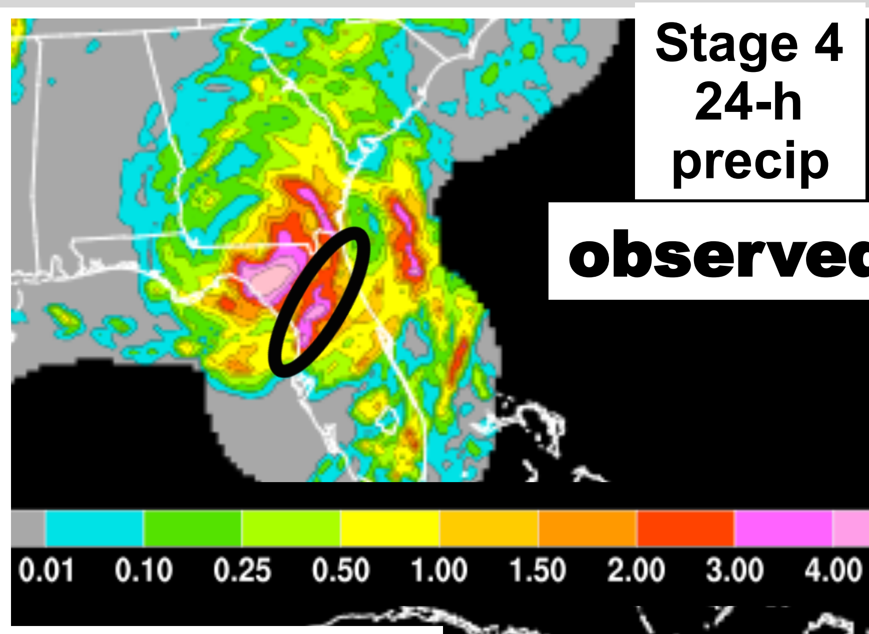
May28-June04 2012 retro runs

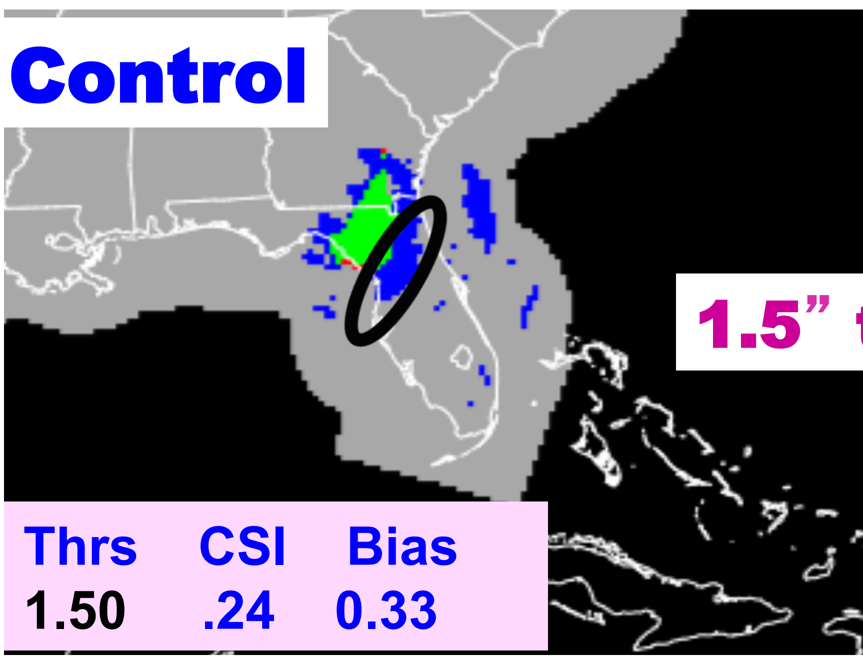
GFS partial cycle at 09z and 21z

Precipitation Verification

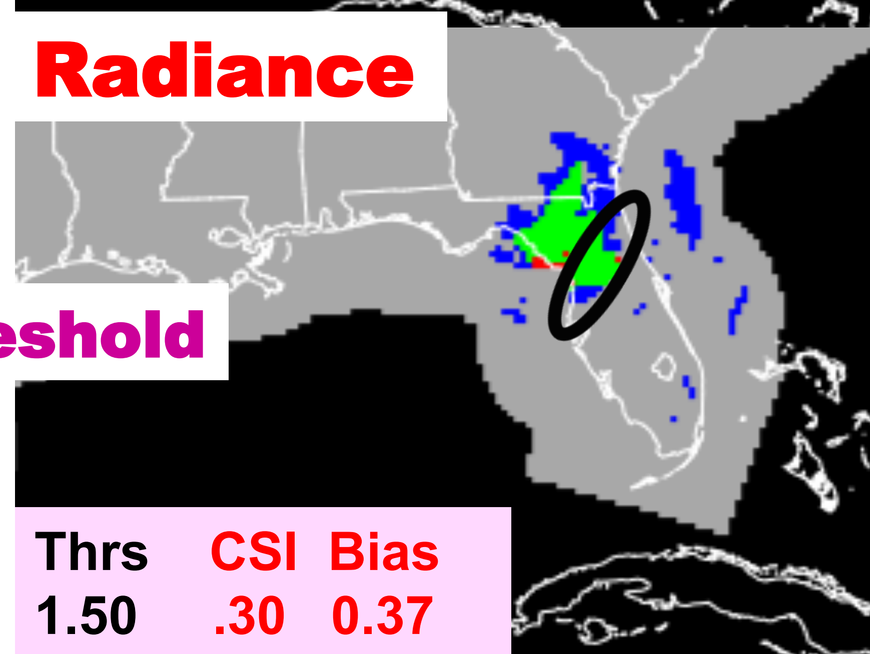
Control vs. **Radiance (RARS included)**

2 x 12h fcst
ending 12z
29 May 2012





1.5” threshold

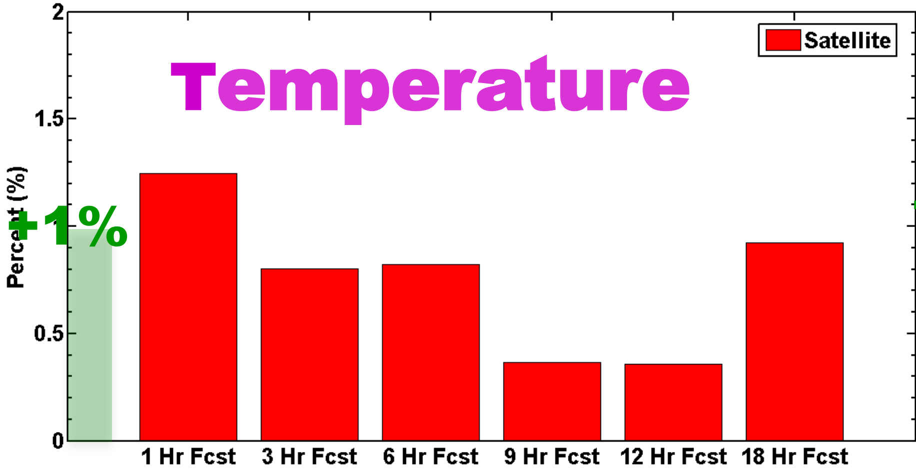


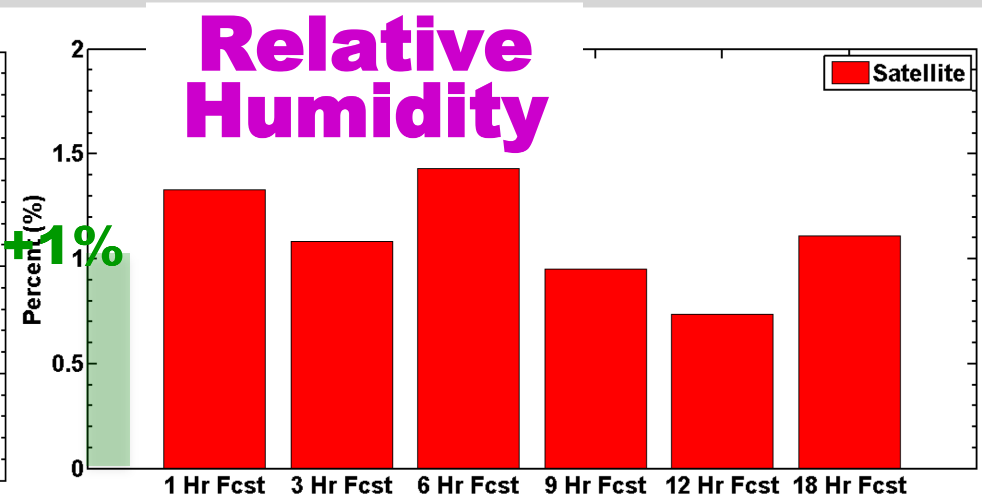
Real-time RAP Experiments

- **Real-time** RAP hybrid systems (RAP V2) on Zeus:
  - 1-h cycling with partial cycle
  - real-time data
- **6 month time period**

  (Jun-July, Oct-Dec, 2013, Jan, 2014)
- **NO radiance**
  - conventional data only
- **WITH radiance**
  - conventional data + operational used radiance data (AMSU-A, HIRS4, MHS)

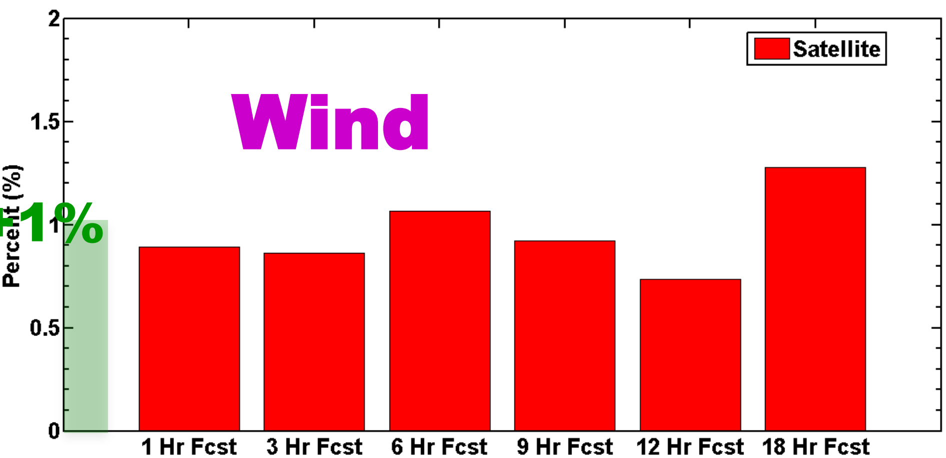
Real-time % improvement from radiance DA





Radisonde verification

6 month REAL-TIME test

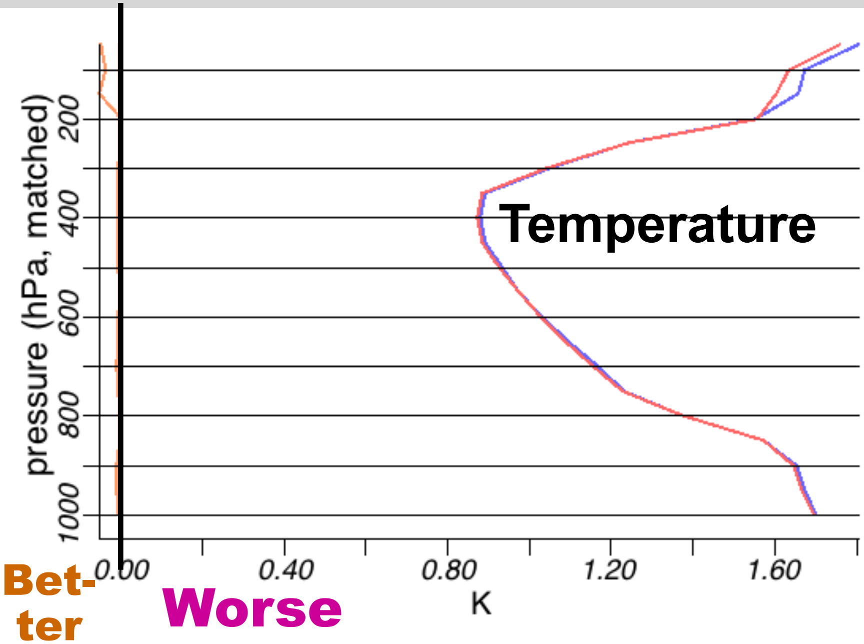


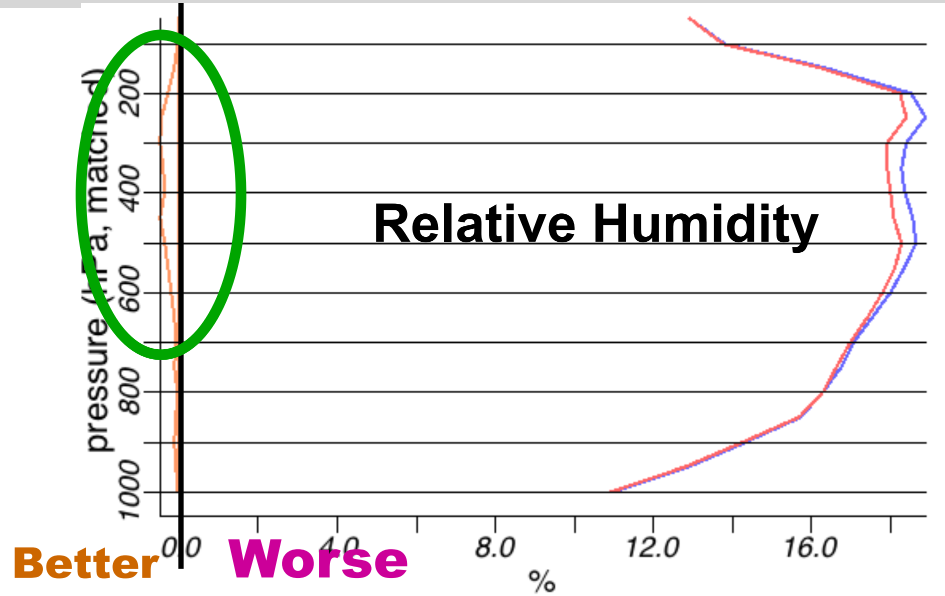
Init Hour	11,23z	9,21z	6,18z	3,15z	0,12z	18,6z
Fcst length	1	3	6	9	12	18
Hrs since GFS	2	0	9	6	3	9

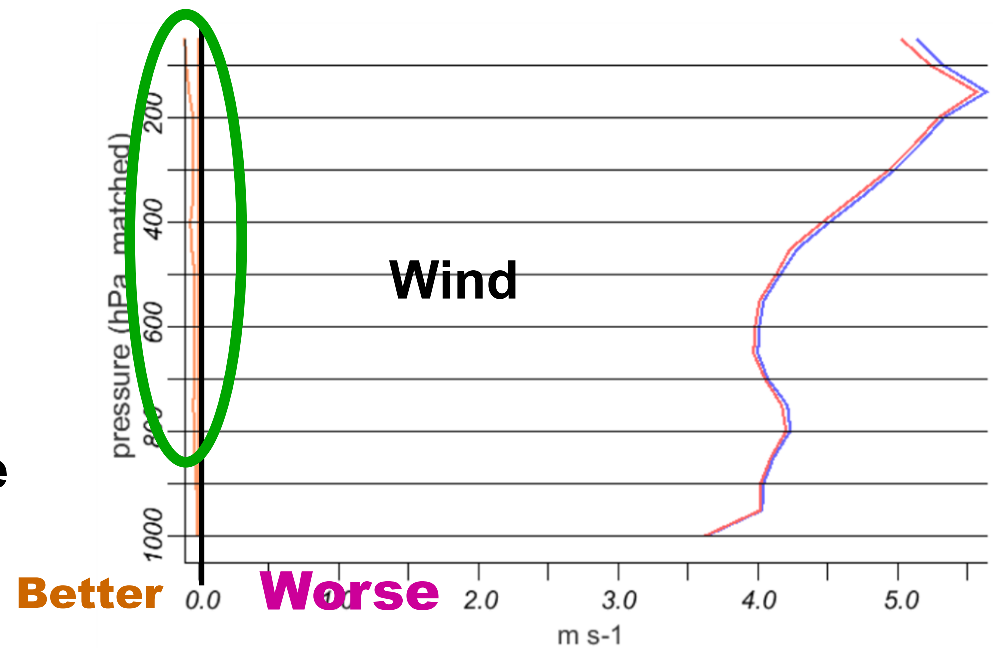
GFS partial cycle at 09z and 21z

100-1000 hPa RMS mean

6-h Forecast RMS Error







WITH radiance

NO radiance

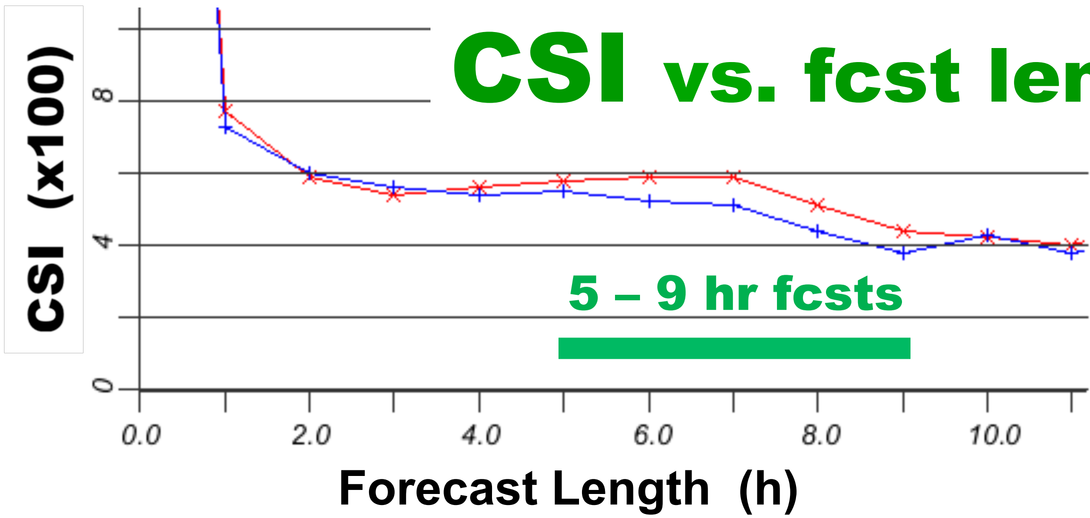
upper-air verification

Real-Time 6-month average

(limited data coverage)

HRRR Radar reflectivity verification

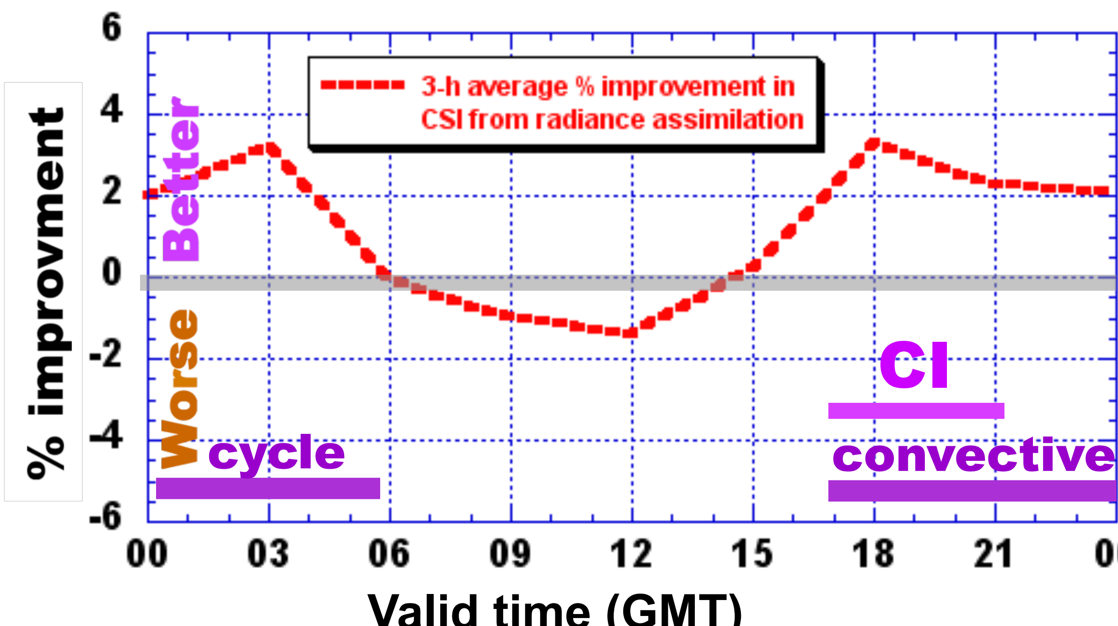
CSI vs. fcst length



WITH RAP radiance

NO RAP radiance

40 dBZ
20 km scale
Eastern US



CSI % improvement from radiance assim vs. valid time of day (all forecast lengths) -- 3 adjacent hourly values averaged to 3-hourly times

30 dBZ
20 km scale
CONUS

May 29 – June 04 2012 (34 HRRR retro runs)

Summary of radiance updates for RAP V3

- Included new sensors/data
  - GOES sounding data from GOES-15
  - amsua/mhs from noaa-19 and metop-b ;
- Included the RARS data (Just on Zeus now)
- Removed some high peaking channels to fit the model top of RAP and removed the ozone channels
- Implemented the enhanced bias correction scheme with cycling

Assimilation of satellite radiance data in morning RAP runs improving mesoscale environment, leading to slightly better HRRR forecasts of convective initiation and evolution

Conclusions

- AIRS and GOES data have slightly positive impact
- RAP real-time radiance data have slightly positive impact and the RARS data provide additional benefits
- 6-month real time runs showed consistent positive impact (around 1%) from radiance data in RAP
- Recommendations for RAP V3 updates (included)

Future work

- Other new data (focusing on hyperspectral data)

  -- ATMS and CrIS from NPP

  -- IASI from metop-a/b

  -- ABI from GOES-R

- Increase RAP model top and model levels for better use of hyperspectral data in regional model and better bias correction (for experiment and research purpose)

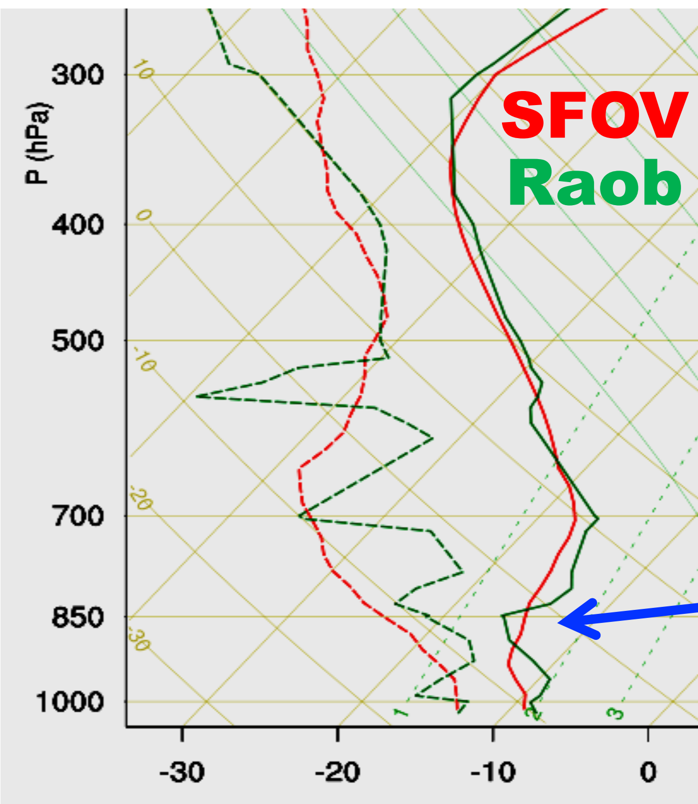
- Real-time data latency problem:
  - Partial cycle strategy
  - Use direct read out data

Assimilation of satellite retrieved soundings

- Single Field of View (SFOV) clear sky soundings derived from CIMSS hyperspectral IR sounder retrieval (CHISR) algorithm (Li et al. 2000)

Can use all channels in retrievals, but retrieved soundings very smooth

Sample retrieved soundings compared to radiosondes



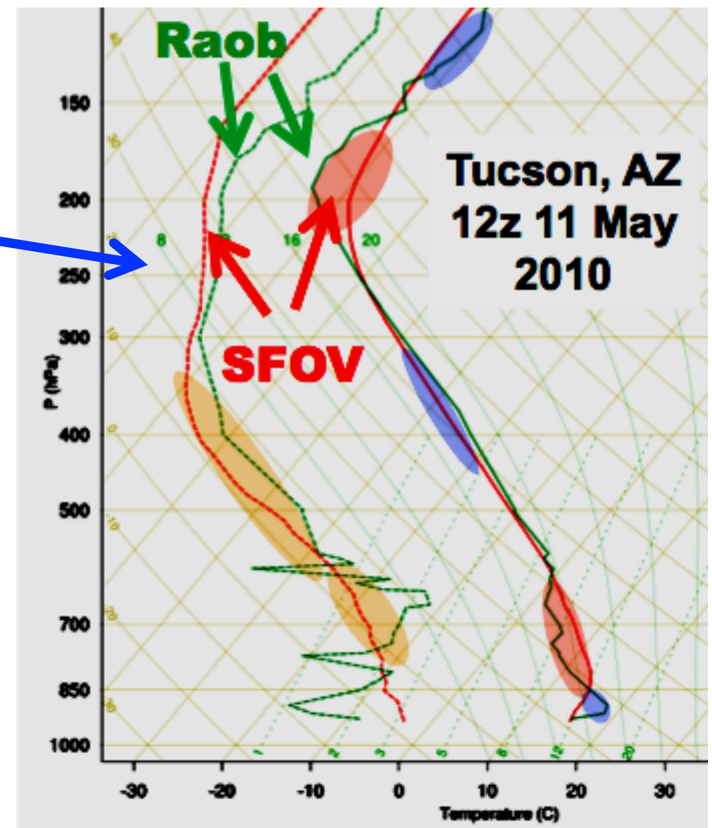
Typical moisture and temperature biases for SFOV

Dry

Warm

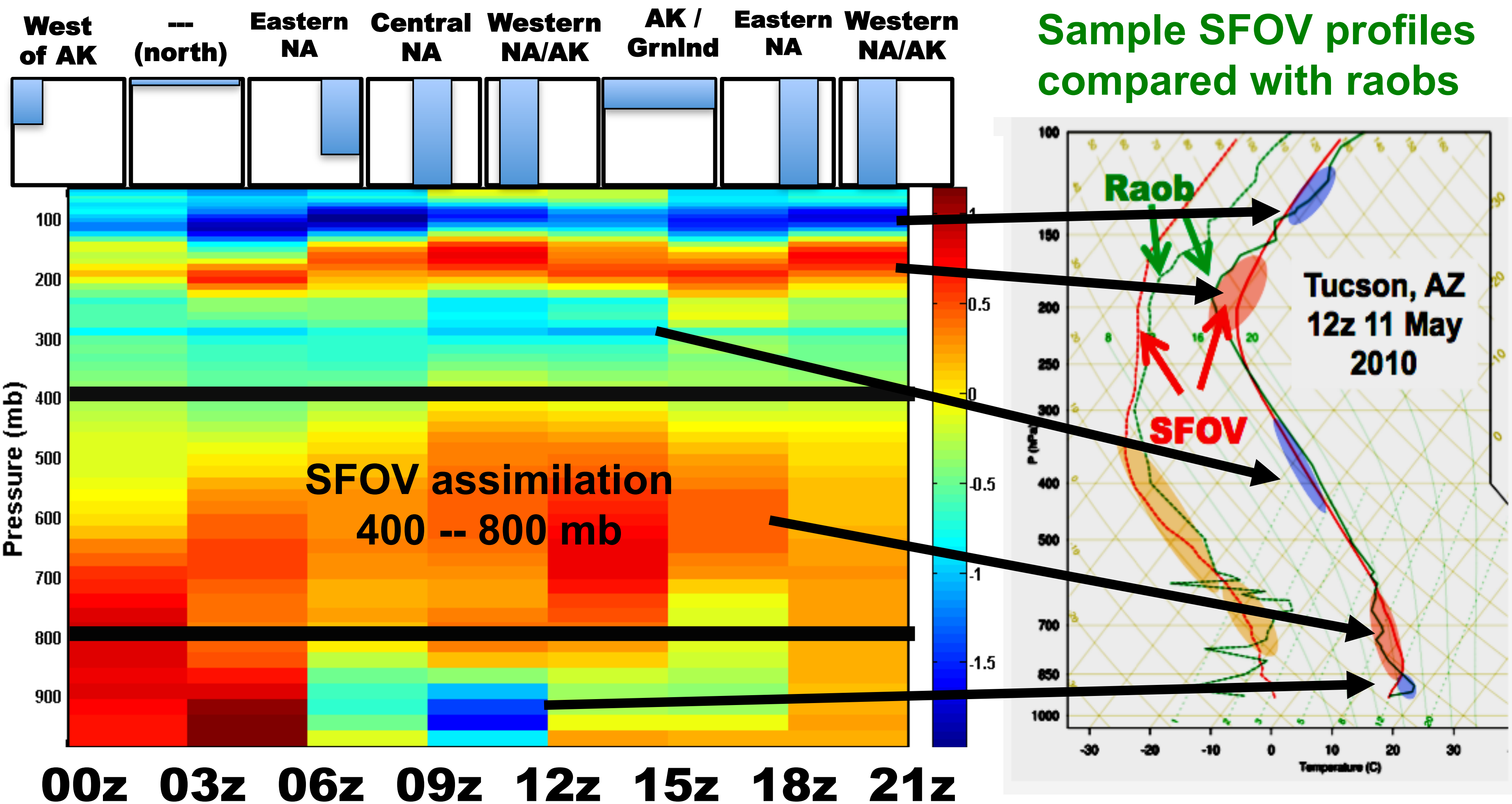
cold

Less vertical structure in SFOV profiles



Diurnal aspects of SFOV T innovations (O-B)

Mean SFOV T innovations – dependence on height, and time of day (horizontal and daily average)



Estimating fraction of data used

short data cutoff times combined with
long data availability latency times leads to
→ minimal satellite data availability

Fraction of data used given by:

$$\boxed{(W/2 - L + C)/W}$$

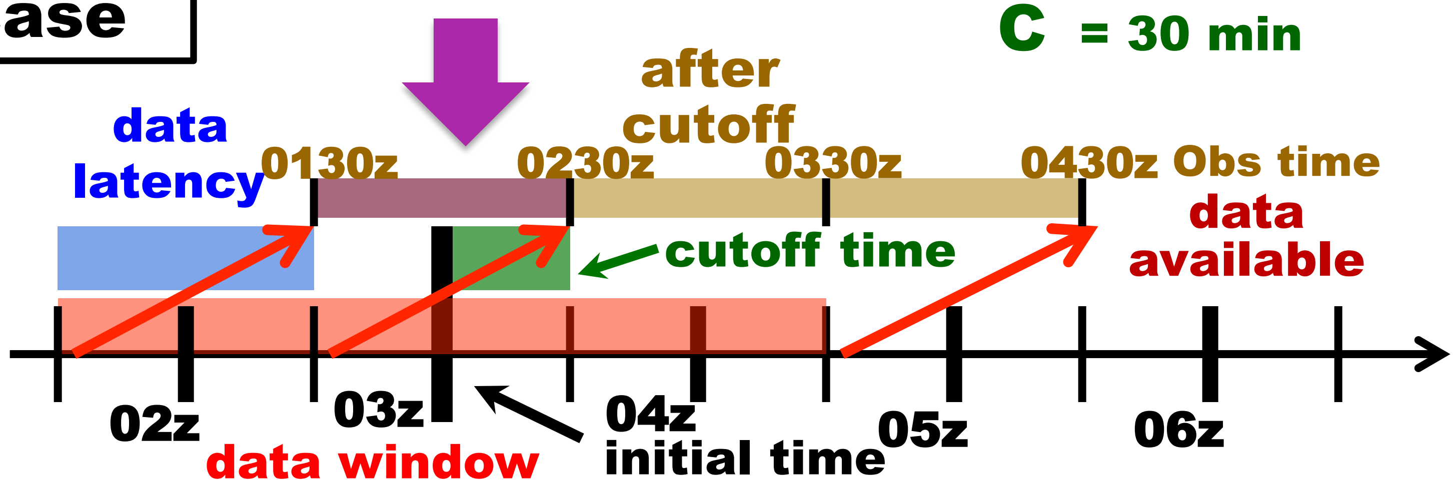
W = Data Window Time
L = Data Latency Time
C = Data Cutoff Time

Sample case

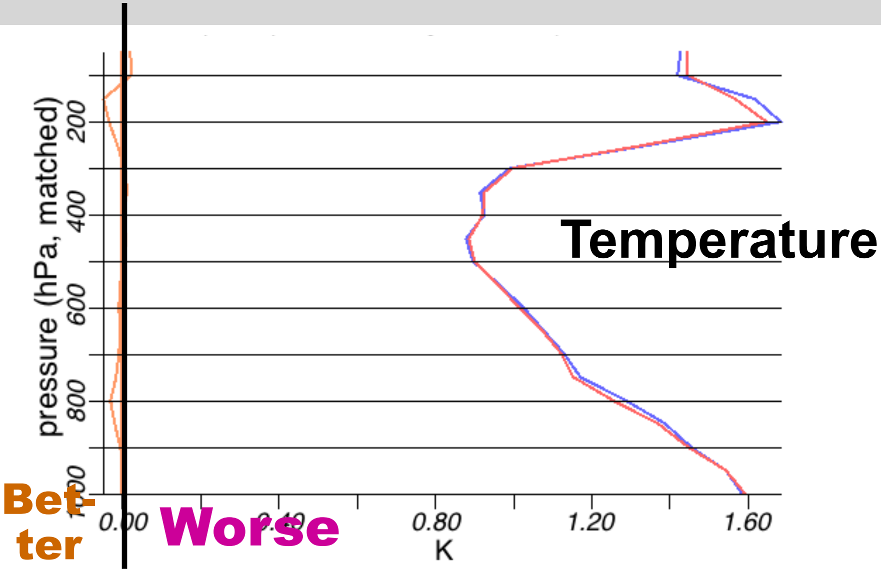
obs used = 33%

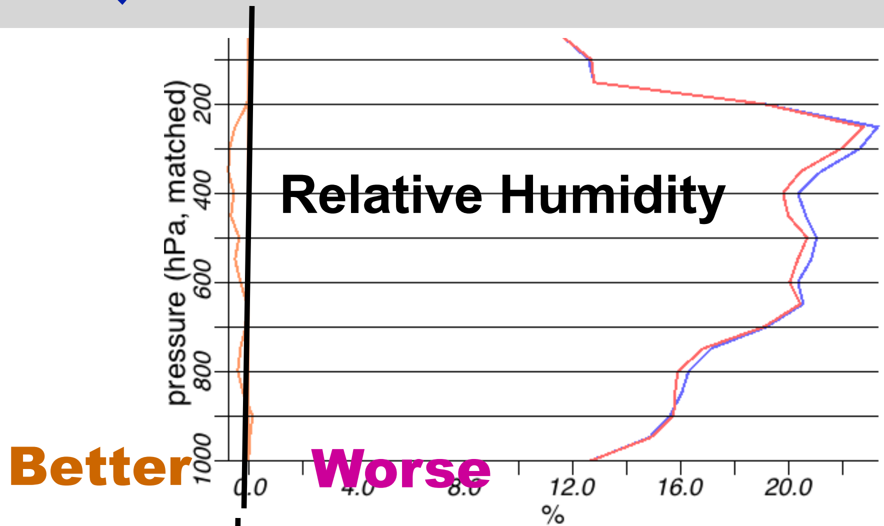
W = 180 min
L = 60 min
C = 30 min

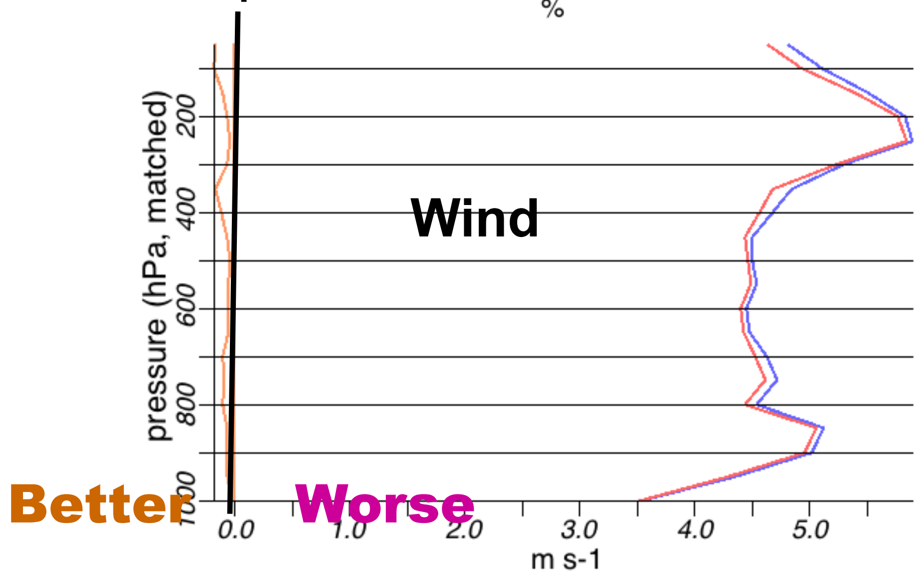
Diagram and equation following Steve Lord



6-h Forecast RMS Error (against raob)







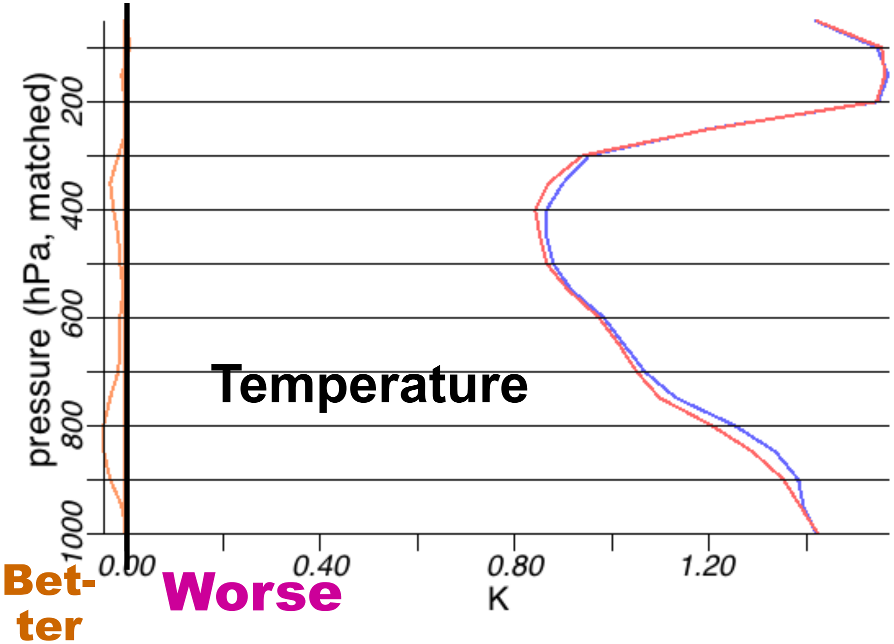
CNTL

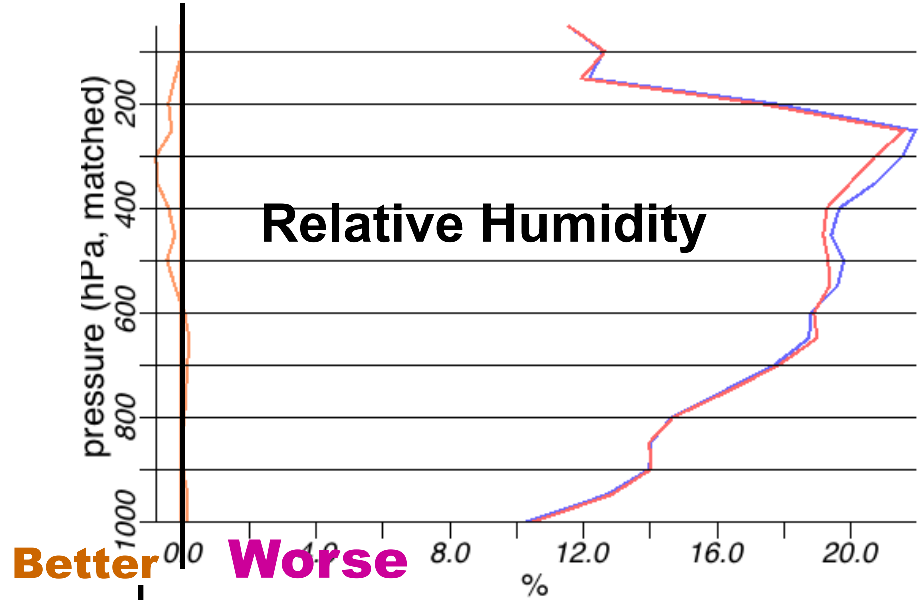
Satellite experiment one (real-time radiance data)

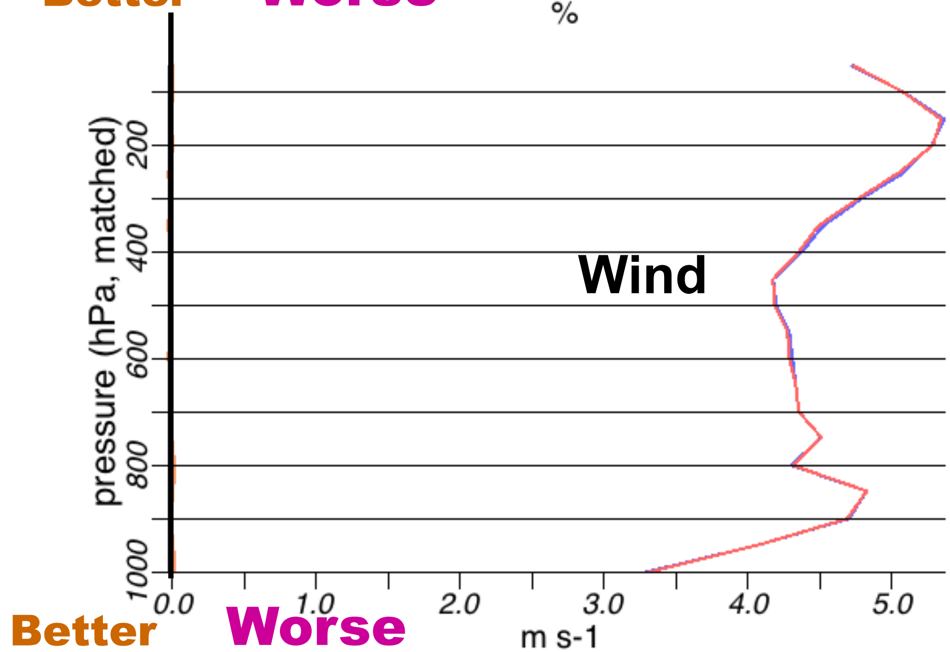
upper-air verification

May28-June04 2012

3-h Forecast RMS Error (against raob)







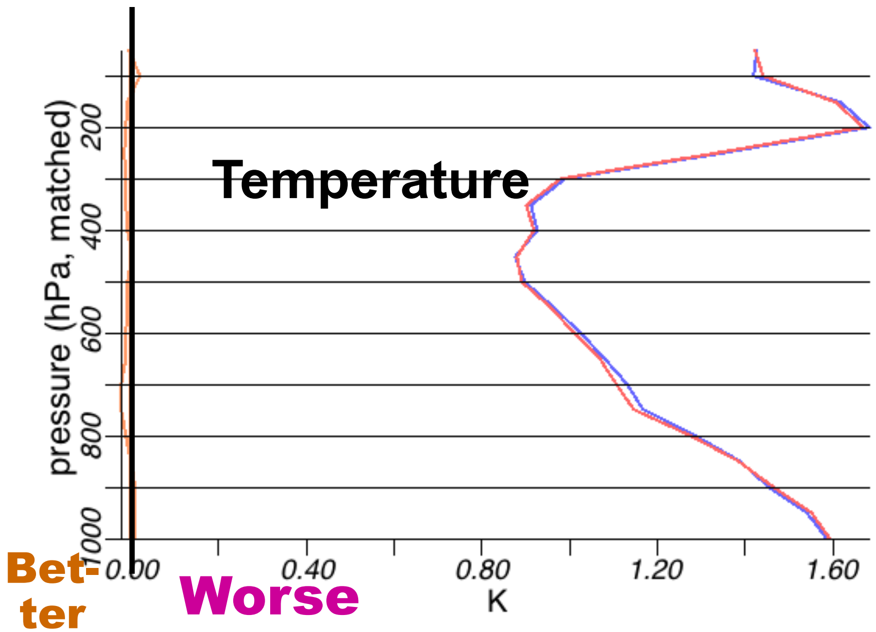
CNTL

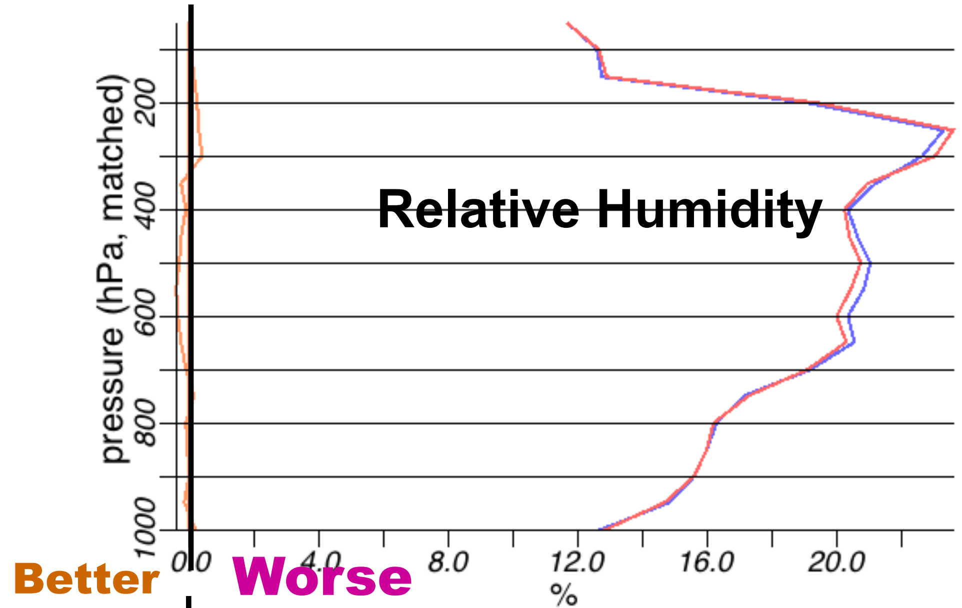
AIRS

upper-air verification

May28-June04 2012

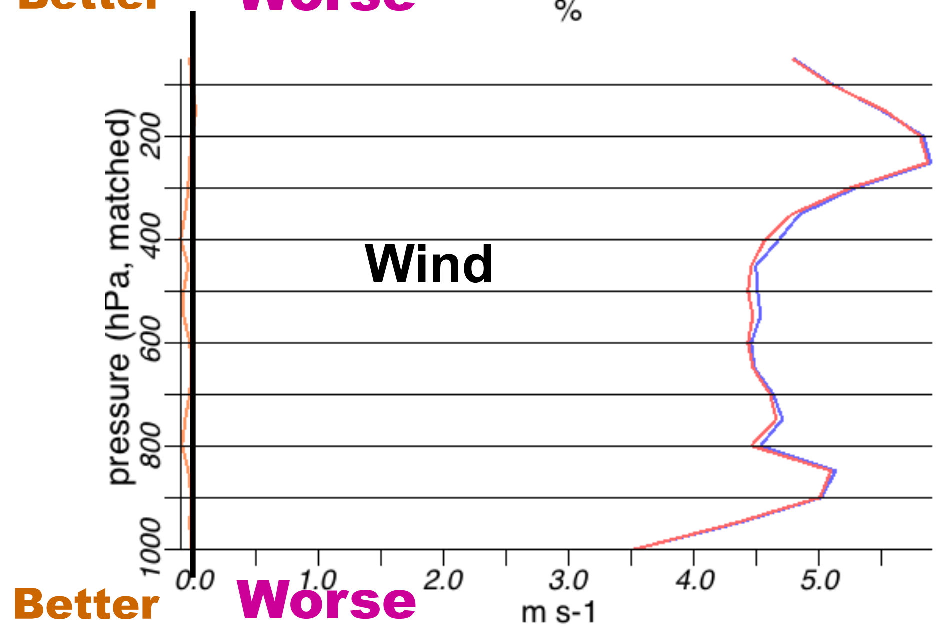
6-h Forecast RMS Error (against raob）





CNTL

GOES

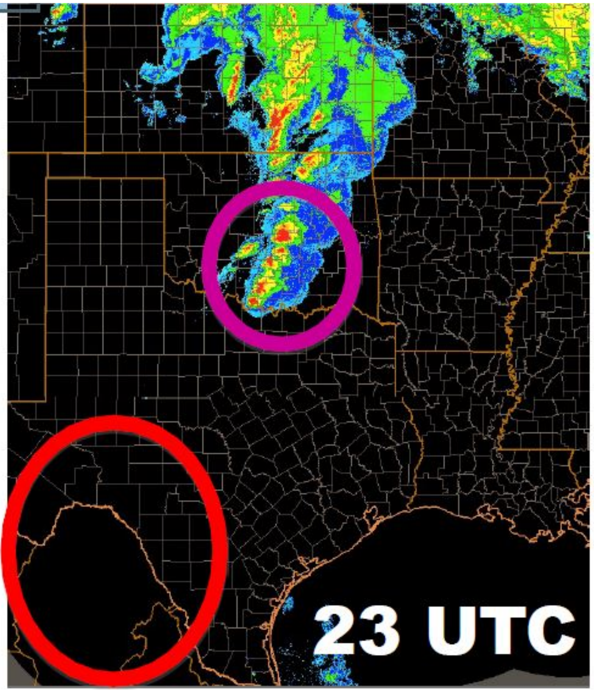


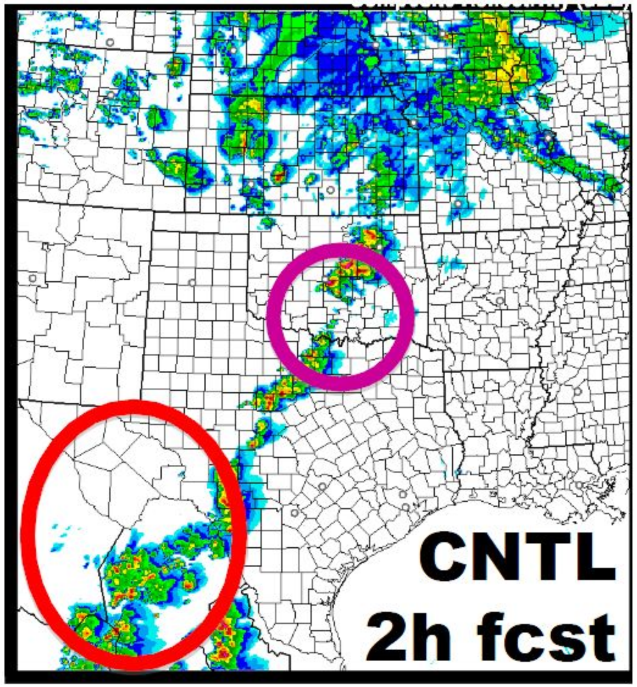
upper-air verification

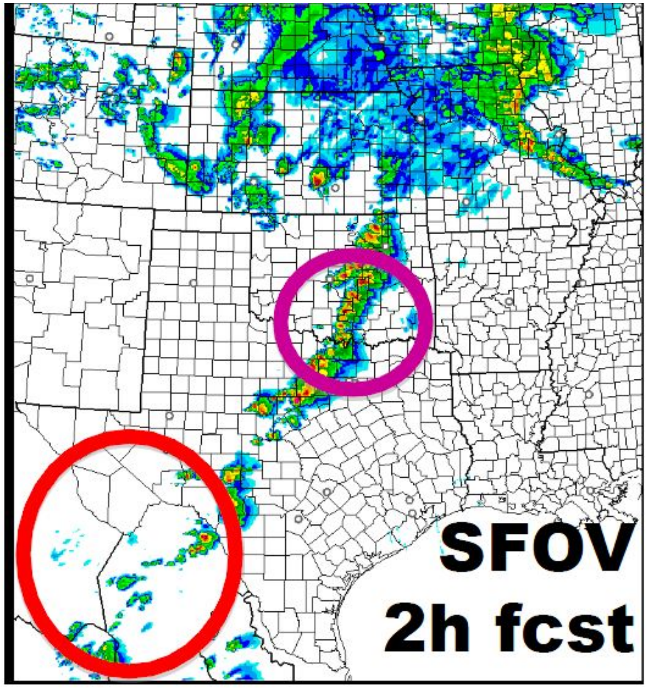
May28-June04 2012

Reflectivity Comparison

Use 9Z + 6h fcst valid 15z 30 May 2012 example???







Observed radar composite reflectivity

HRRR forecast reflectivity initialized from control RAP

HRRR forecast reflectivity initialized from AIRS SFOV RAP run

Channel selection because of low model top

Jacobian calculation in CRTM to find problem channels

- The CRTM K-matrix model (Jacobian model) computes the radiance derivatives with respect to the input-state variables, such as temperature and gas concentration
- Forward model $R = F(x)$

The matrix H contains the jacobian element $\frac{\partial R_i}{\partial x_j}$

- TL model $R_{TL} = \mathrm{H} x_{TL}$
- AD model $x_{AD} = \mathrm{H}^T R_{AD}$
- K-matrix model $x_k = [h_1 R_{K,1}, h_2 R_{K,2}, \ldots, h_m R_{K,m}]$
- $R_{K,i}$ is the input K-matrix radiance input variable and h_i is the transpose of the ith row of the H matrix:

$$h_i = \left[\frac{\partial R_i}{\partial x_1}, \frac{\partial R_i}{\partial x_2}, \ldots, \frac{\partial R_i}{\partial x_n}\right]^T$$

- Setting $R_{K,I} = 1$ for (i=1,….,m), the matrix x_k returned from the K-matrix model contains the Jacobians